Microgravity Experiments to Evaluate Electrostatic Forces in Controlling Cohesion and Adhesion of Granular Materials

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Background

- Previous microgravity experiments aboard USML-1 and -2 led to the current plan to test a fundamental hypothesis that the electrostatic behavior of dielectric grains may be strongly influenced by previously unrecognized (long-range Coulombic) dipole-dipole interactions

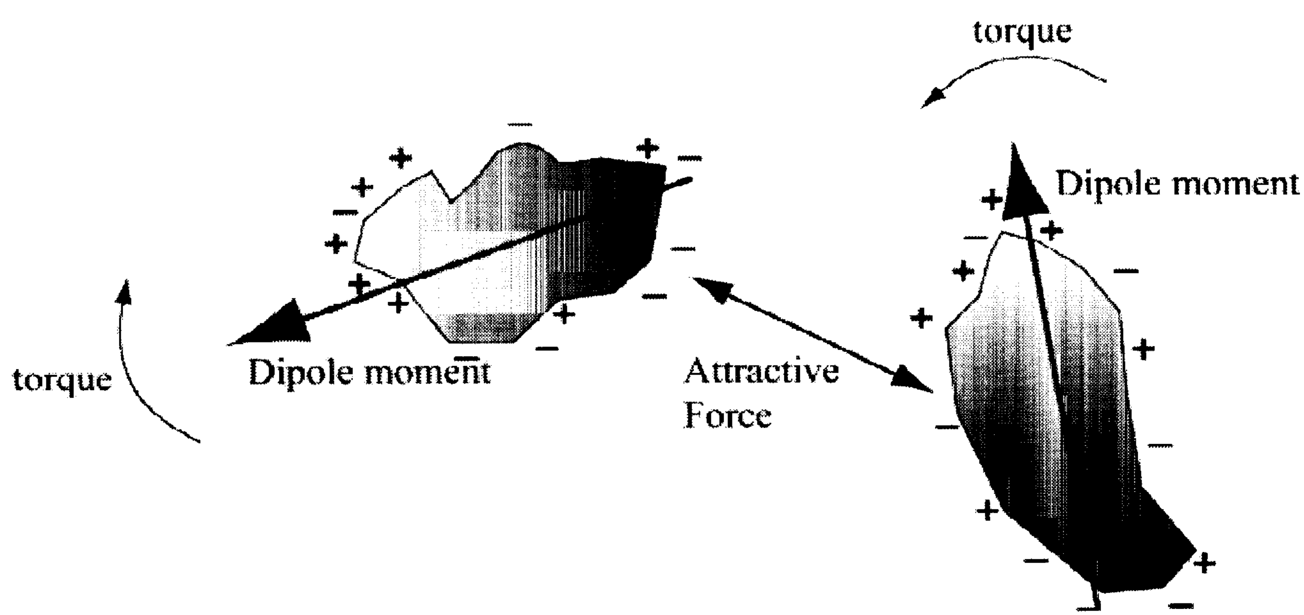
- In USML experiments, it was determined that a cloud of untreated dielectric sand grains always aggregates (virtually spontaneously) into filamentary structures of single-grain width, but up to tens of grains in length. Conversion from monodispersion to aggregation is driven by ***Coulombic viscosity***, and constitutes an ***electrostructural phase change*** of granular matter. Results strongly implied that grains had natural electrostatic ***dipolarity***, even though they had only random surface charges from triboelectrification.

- Electrostatic grain interactions (of long-range) are generally perceived to result only from net charge. Our current hypothesis suggests that there is another long-range electrostatic force at work.

Applications of Research

- Electrostatic **aggregation** (particularly dipole-mediated), might be pervasive and affect many types of granular systems:
  - Astrophysical-scale systems such as interstellar nebulae, protoplanetary dust and debris disks, and planetary rings
  - Planetary-scale systems such as debris palls from meteorite impact, volcanic eruptions, and aeolian dust storms
  - Industrial-scale systems in mining, powder and grain processing, pharmaceuticals, and smoke-stack technologies.
- Electrostatic **adhesion** of dust and sand on Mars is of concern because of its potentially critical importance to human exploration. Adhesion of martian surface materials will affect design and performance of spacesuits, habitats, processing plants, solar panels, and externally exposed equipment such as surface rovers or communication and weather stations.

Hypothesis



- Non-uniform distribution of charge carriers on a grain surface creates a dipole moment on the grain.
- Interaction of these dipole moments creates both a torque and an attractive force between the grains.
- No net surplus of charge carriers is required.

Microgravity Approach

How can the electrostatic character of a single grain be interrogated in a way that does not alter the parameters being measured ?

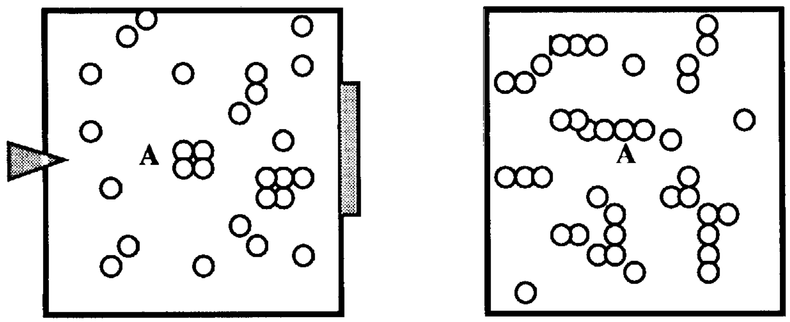
- Allow grains and aggregates to express their interactions through unconstrained motions (acceleration/drift rates, repulsions, attractions) while they are freely suspended under microgravity conditions as part of a dispersed cloud

- Induce grain/aggregate motions by controlled electrical (homogeneous & inhomogeneous) fields and variable electrical neutralization of the grain cloud

- Rotational & translational motions of filamentary aggregates are diagnostic expressions of the forces at work. Different electrostatic forces (inductive, monopole, dipole) cause different types of motion, thus enabling each force to be isolated for study

- Merit of microgravity experimentation is borne out by the fact that the dipolarity of grains was discovered in previous Space Shuttle experiments

Design Concept For Experimental Cells

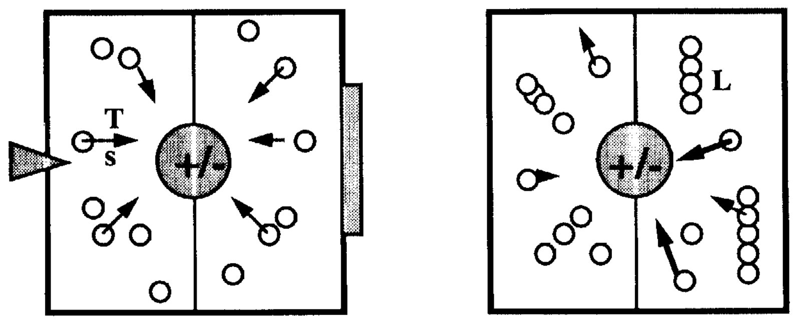


Grains neutralized

CONFIGURATION A

Van der Waal effects:

Modules fitted with AC corona only

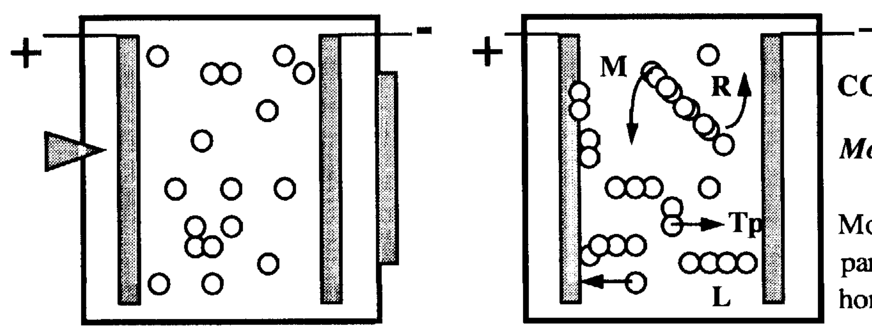


Grains neutralized

CONFIGURATION B

Dielectric induction:

Modules fitted with chargeable metal spheres (coated and uncoated) for inhomogeneous field



Grains neutralized

CONFIGURATION C

Monopole/dipole:

Modules fitted with parallel plates for homogeneous field

Dipole model tested by separating dipole forces from Van der Waals, dielectric polarization and monopole (net charge) effects on aggregation, and by studying charged versus neutralized grains. Electrostatic aggregates manipulated by charged surfaces to determine dipole moments reflected by induced aggregate orientations.

Experiments conducted in series of small (150 cubic cm) cells used previously in USML flights. Grains and aggregates observed by 3-D video imagery – the primary data source.

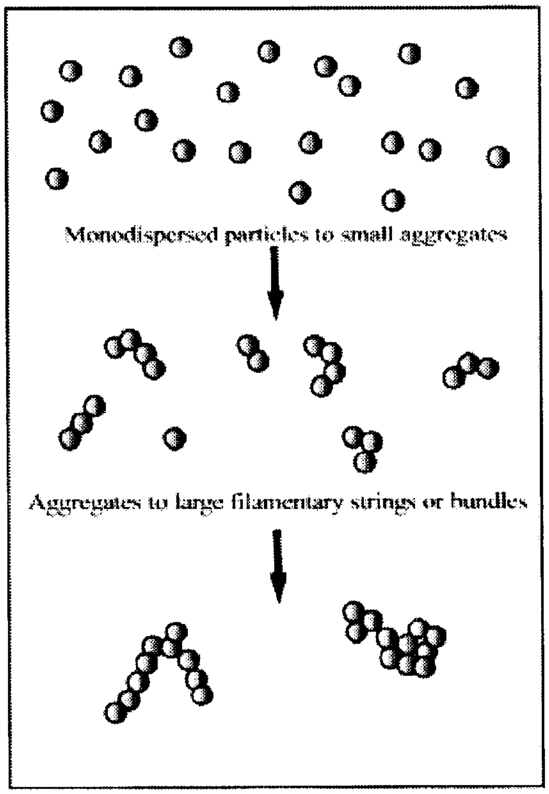
Some quantifiable parameters
R = rotation rate between plates gives dipole moment. Tp = translation rates to plates gives monopole (net charge) and charge randomness.
Ts = translation rates to spheres; sigma values give randomness of charge distribution.
L = length of aggregate vs. degree of applied neutralization. A = aspect ratio (shape of aggregates) vs. degree of neutralization.
M = mass attached to a plate as function of neutralization/voltage

Investigation Strategy

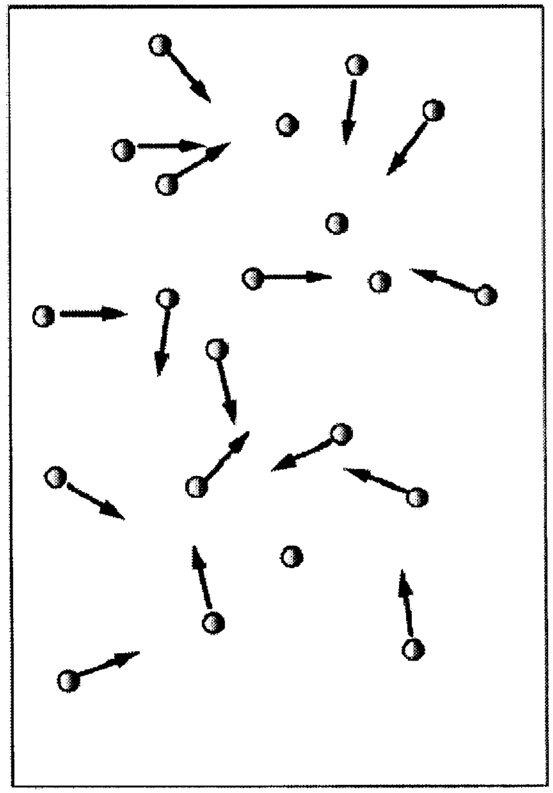
Investigating the dipole model, aggregation, and related electrostatic phenomena, involves two investigative levels. The first seeks to PROVE the dipole concept and develop fundamental understanding of electrostatic processes. The second seeks to define the IMPLICATIONS of dipole effects and other aggregation phenomena through analytical and computational modeling. Both strategies currently involve activities in the following areas:

- Engineering design concepts for a microgravity experiment
- Definition of science requirements and experimental methods
- Computer modeling to explore grain behavior, and as a tool for calibration of engineering designs
- Analytical modeling to explore scientific applications of the dipole/aggregation concepts
- Corroborative laboratory experiments on grain charging as a test of dipole manifestations

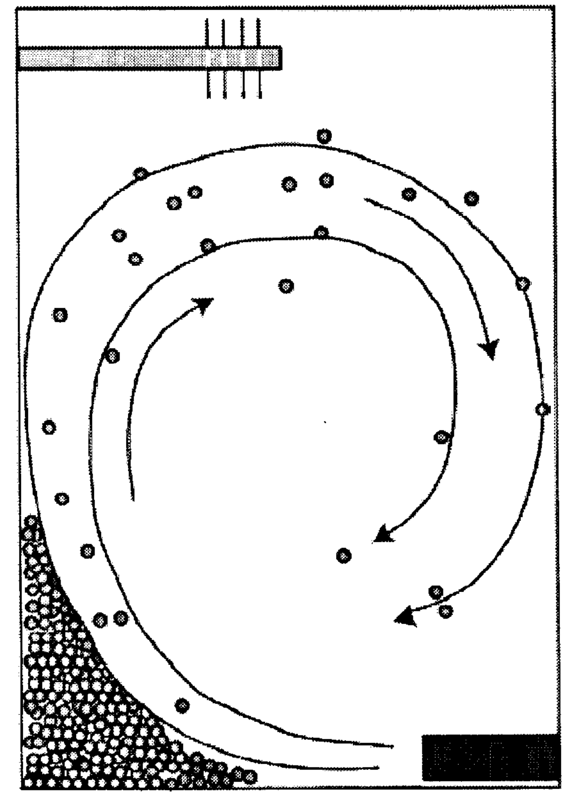
Progress: Development of Analytical, Computational and Experimental Tools



Analytical models developed for Coulombic viscosity, electro-structural phase changes, and aeolian transport.



Computer models being developed for aggregation and fluidized granular flow.



Lab experiments to measure effects of triboelectric charge saturation on grains using RF and eletrometer methods.

Progress: Science Requirements and Engineering Concepts

- At LeRC, an experiment development team has been formed to identify "tall poles" in the experiment design. In concert with the PI, the team has quantified science requirements, and will conduct proof-of-concept tests as necessary. The team will establish carrier options based on these science requirements. Several concepts have already been proposed and are being reviewed regarding automated verses crew-interactive test apparatus.

- Science data are obtained from rates of formation, drift, and rotation of aggregates which form during the experiment. The challenge for these measurements is to provide a well-characterized "electrostatically clean" test cell in which an imaging system records 3-D grain behavior. Other issues concern initial dispersion of grains, control of local cloud density, variable voltage for the aggregate "manipulators", and ability to neutralize charged grains. These issues need to be addressed in proof tests in the low-g environments of the KC-135 aircraft and drop tower experiments.